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Effects of Time Averaging on Noise Floor in Distortion Product Otoacoustic Emissions

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Otoacoustic emissions (OAEs) - sounds originating in the cochlea that are measured in the external canal (Kemp, 1978) - show promise for clinical use, especially screening, when determining the function of outer hair cells, which are now thought to be the site of production of these emissions. Two types of OAEs are being studied as they apply to hearing screenings: transient emissions and distortion product emissions (DPOAEs). The present study was undertaken to examine this type of emission. DPOAEs, defined as "acoustic energy in the ear canal arising from the nonlinear interaction of two simultaneously applied pure tones within the cochlea" (Lonsbury-Martin et al., 1993), can be found in nearly all normal ears.

DPOAEs have several advantages when testing peripheral auditory function: they are objective and measured easily with noninvasive techniques; they require relatively short test times; they are frequency specific; and they are present in nearly all ears with normal outer hair cell (OHC) function (Lonsbury-Martin et al., 1993). It has been reported (Zurek, 1992) that DPOAEs can also be obtained at least eight times faster than transient-evoked emissions.

Noise levels in the ear are known to affect the detectability of DPOAEs (Lasky et al., 1992), particularly for low presentation levels. In order to more clearly detect possible emissions, a low noise floor is desirable. Noise floor can be reduced a variety of ways. Testing in a sound booth, reducing the noise of the equipment through technological design, and signal averaging can all play a role in lowering the noise floor (Lasky et al, 1992). Another way to reduce the noise floor is to increase linear averages in the time domain (Popelka et al., 1993). Popelka et al. (1993) used 8000 samples and produced noise floors as low as - 40 dB SPL. The forty-five minutes required to obtain an input-output function with this number of time averages is clearly not clinically practicable.

PURPOSE

The present study examines the effect of three time averages (eight, thirty-two, and 128 samples) at the frequencies 1 kHz, 2 kHz, and 4 kHz on the noise floor so that the clinical feasibility of these time averages may be assessed. A secondary related goal was to determine what combinations of presentation levels and frequencies reveal DPOAEs a sufficient amount above the noise floor to be considered valid.

METHODS

Subjects

Ten graduate students, nine females and one male, with a mean age of 24.4 years, were tested in the study. All were screened for normal tympanometric results (-200 to +200 daPa) and normal hearing (less than or equal to 25 dB HL) at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Pure tones and tympanograms were administered at Central Institute for the Deaf in sound booths. Subjects with normal hearing and no apparent middle ear pathology were recruited since such conditions are known to affect the production of emissions.

Measurements

All DPOAE measurements were obtained using a Virtual Model 330 system in the hearing aid dispensary at St. Louis Children's Hospital. A response curve across the frequency range of 500 to 8000 Hz preceded input-output functions at 1, 2, and 4 kHz for each subject. For input-output functions, the geometric means of f1 and f2 were 1000 Hz, 2000 Hz, and 4000 Hz with an f2:f1 ratio of 1.21. Ratios in this area generally produce the largest 2f1-f2 distortion products for higher level stimuli (Popelka et al., 1993). The stimulus level was varied from 30 to 75 dB SPL IN 5 dB steps. Three time averages - 8 samples, 32 samples, and 128 samples - were collected for each frequency.

RESULTS AND DISCUSSION

Past studies have shown the noise floor to become increasingly lower as the number of time averages becomes greater; the amount of noise floor reduction is proportional to the square root of the number of samples (Zurek, 1992). Popelka et al. (1994, submitted) suggest the noise floor should be reduced by 3 dB per doubling of samples. Figure 1 shows the total level of noise floor reduction for each frequency. This "3 dB per doubling" phenomenon is visible in the present study at 2 kHz, where the reduction in noise floor is 11.39 dB SPL, which is close to the theoretical prediction of 12 dB. At both 1 kHz and 4 kHz, where the reductions are 8.95 dB SPL and 7.78 dB SPL, respectively, the reduction is clearly less than 12 dB SPL. Only ten ears were used in this study, representing only a small sample. Of the individual subjects, however, none produced a 12 dB reduction in noise floor at all frequencies. Four showed the reduction at 1 kHz, four at 2 kHz, and only one at 4 kHz. Table 1 shows the mean, as well as the highest and lowest, noise floors at all frequencies and time averages.

Figure 1 also shows that the noise floor is highest at 1 kHz, a fact which was expected and may be attributable to low-frequency ambient noise in the test room. The noise floor was higher at 4 kHz than at 2 kHz, possibly due to system noise interacting with the measures at the higher frequency. The rise in noise floor at higher test frequencies is present in the data reported by Lonsbury-Martin et al. (1990).

Figures 2, 3, and 4 show the noise floors and DPOAEs at each time averaging (8, 32, and 128) for each test frequency (1 kHz - Figure 2; 2 kHz - Figure 3; and 4 kHz - Figure 4). If the noise floor and DPOAEs do not interact, the DPOAEs should be the same for 8, 32, and 128 time averages. This does not appear to be the case. At all three test frequencies the DPOAEs for 8 time averages are elevated relative to 128 time averages, particularly for presentation levels less than 70 and 75 dB SPL. Thus it appears that DPOAEs and the noise floor do interact to some degree. This is seen clearly in Figure 3 for 2 kHz at 55 dB SPL where invalid conclusions may be drawn concerning absolute DPOAE level if 8 or 32 time averages were obtained.

Figures 5, 6, and 7 illustrate the level of DPOAEs relative to the noise floor for presentation levels at 50, 55, and 60 dB SPL, respectively. If an 11 dB criterion (DPOAE above noise floor) is applied as suggested by Popelka et al (1994, submitted), as shown in Table 1 , no valid measures were obtained at 50 dB SPL presentation level with up to 128 time averages for 1, 2, or 4 kHz. At 55 dB SPL presentation level, criterion was met at 1 kHz for 128 time averages. At 60 dB SPL criterion was met for 1 kHz (128 time averages) and 4 kHz (32 and 128 time averages). At 4 kHz for 60 dB presentation level no advantage of 128 to 32 time averages was observed. Thus, for 4 kHz at a 60 dB SPL presentation level, clinical time could be reduced by using 32 time averages instead of 128 time averages.

For clinical situations, where several data points are obtained, a less conservative criterion such as 5.5 dB (i.e., one standard deviation) may be appropriate. As illustrated in Figures 5, 6, and 7 and Table 2, if 5.5. dB is the criterion, only eight time averages would be required to elicit a response at 1 kHz at 60 dB SPL presentation level, 2 kHz at 55 dB SPL presentation level, and 4 kHz at 60 dB SPL presentation level. Additional composite and individual graphs for time averages and frequencies are located in Appendix A.

CONCLUSIONS

Because noise floor level, DPOAE level, and noise floor reduction are frequency dependent, it would maximize efficiency to develop a separate set of required time averages for each frequency. At high stimulus presentation levels (70 and 75 dB SPL) DPOAEs appear convergent for the time average samples tested. However, if lower level stimuli are of interest a low noise floor is needed to record valid emissions. If a strict criterion, such as 11 dB SPL above the noise floor is used to determine validity for presentation levels in the 60 dB SPL range, 128 samples are necessary at 1 kHz and other relatively low frequencies because of the prevalence of ambient noise. Fewer samples may be used at middle frequencies, such as 2 kHz and 4 kHz. If a less strict criterion such as 5.5 dB SPL is adopted, eight samples are generally enough to produce valid emissions for normal hearing young adult subjects at a 60 dB SPL presentation level.

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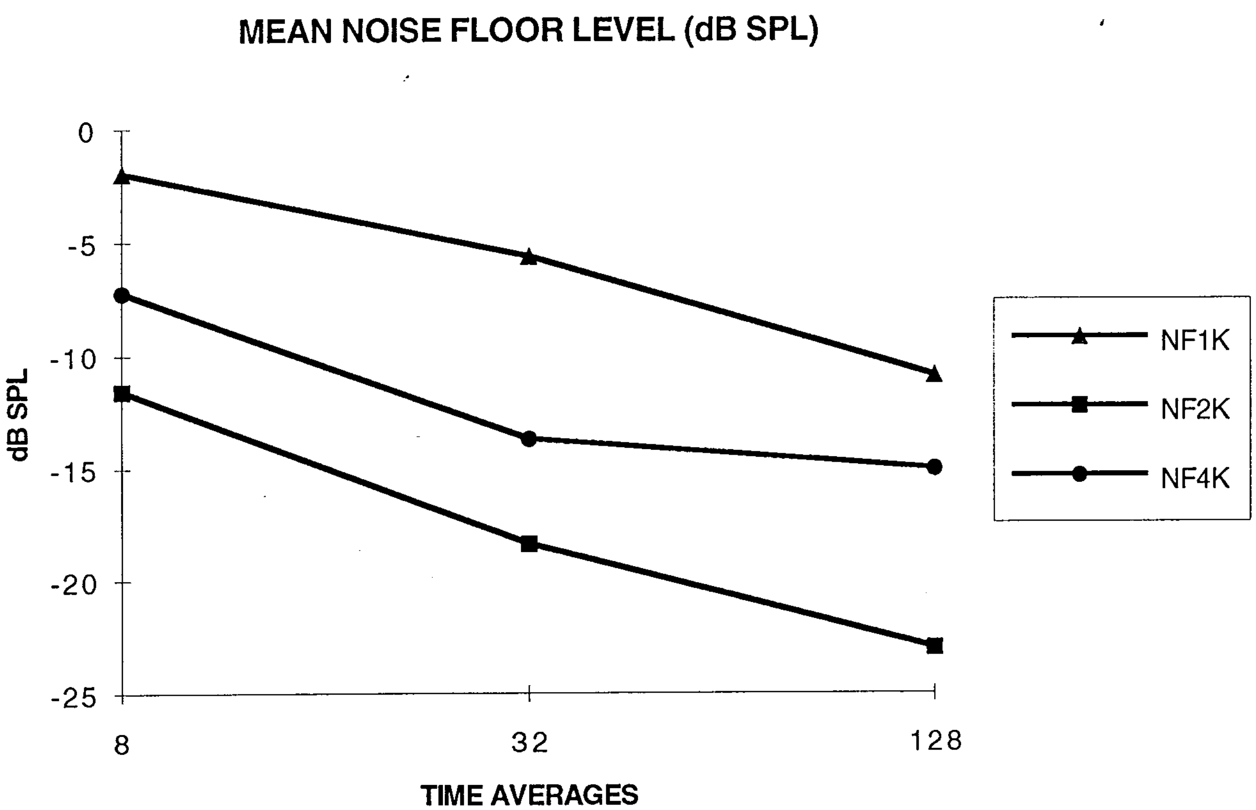


Figure 1. *Mean noise floors for each frequency at each time average .*

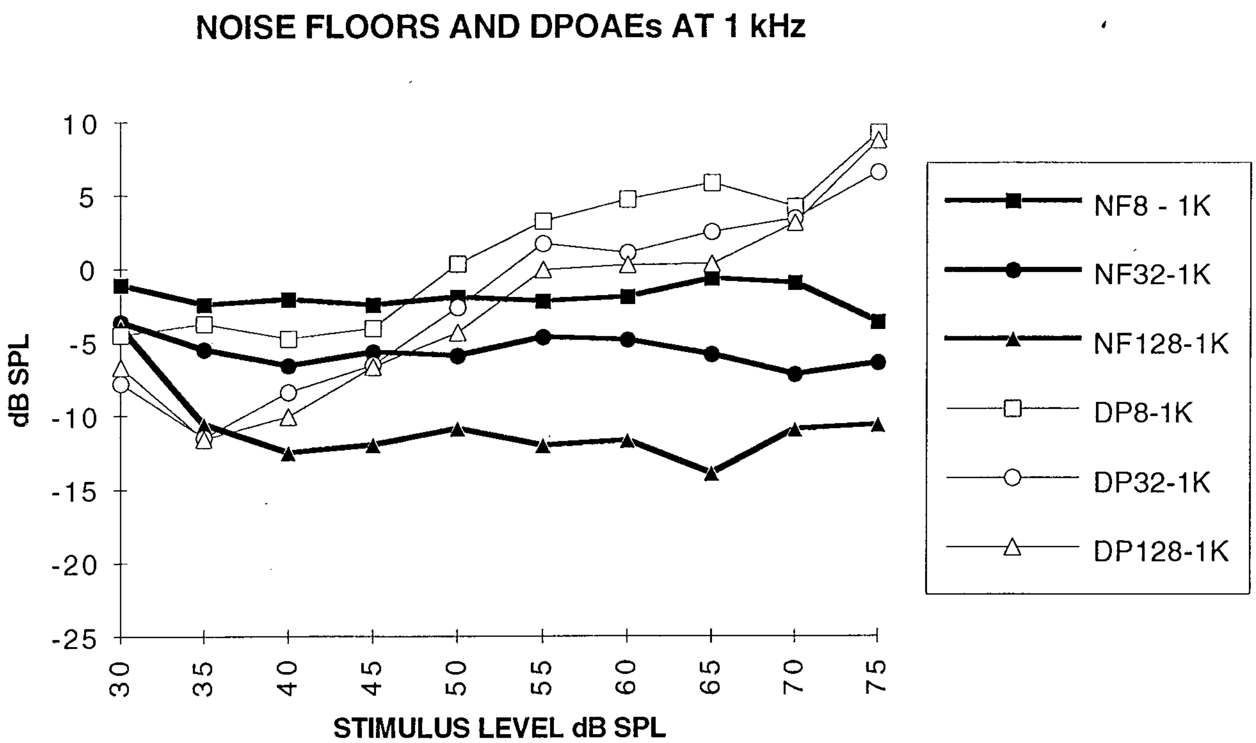


Figure 2. *Noise floors and DPOAEs for 1 kHz at each time average.*

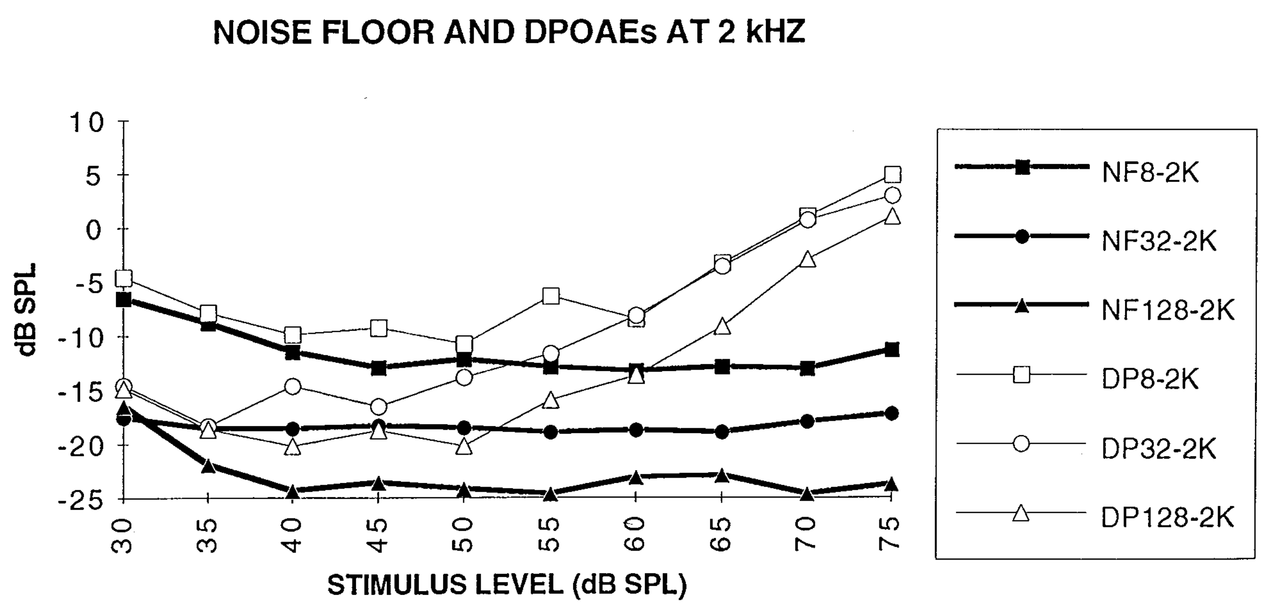


Figure 3. *Noise floors and DPOAEs for 2 kHz at each time average.*

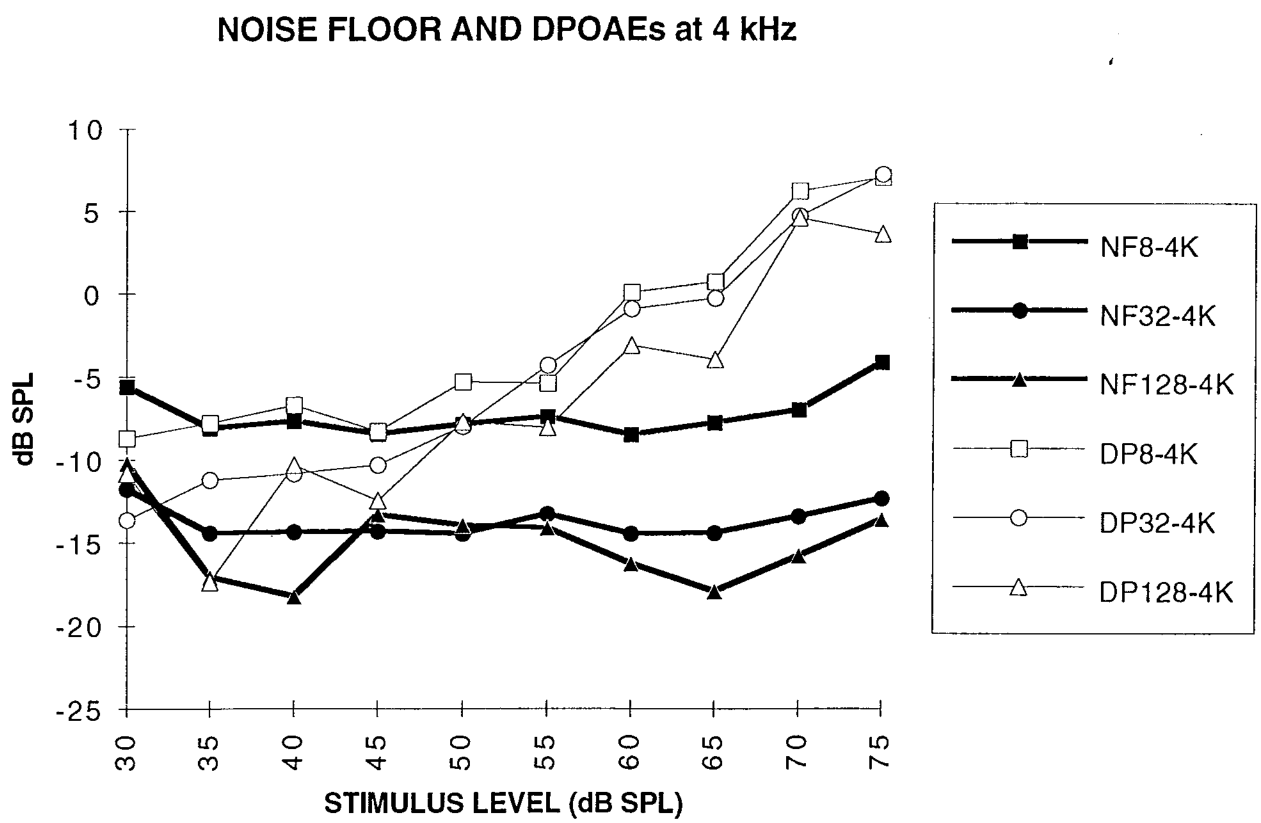


Figure 4. *Noise floors and DPOAEs for 4 kHz at each time average.*

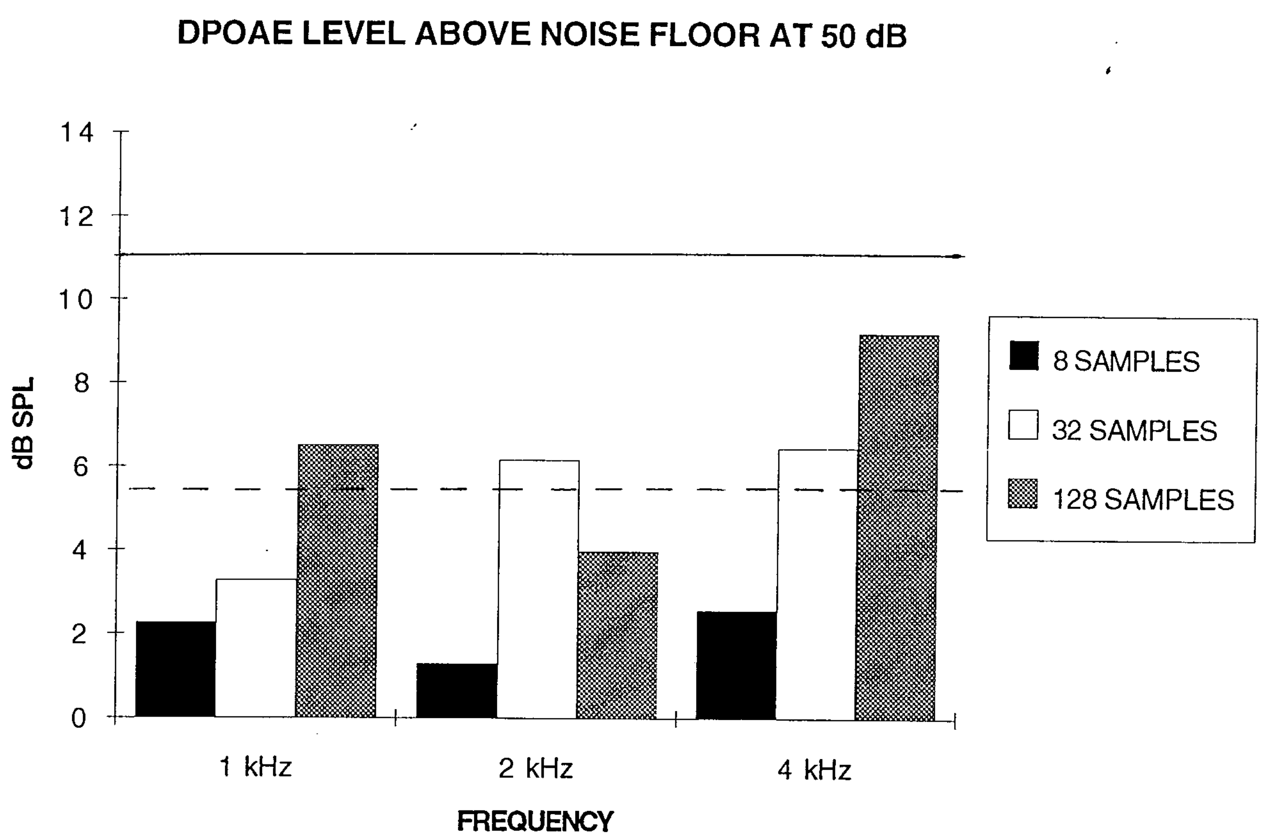


Figure 5. *DPOAE level above the noise floor for each frequency and time average at 50 dB SPL stimulus intensity level. The horizontal dotted line represents a 5.5 dB SPL criterion; the solid line represents the 11 dB SPL criterion.*

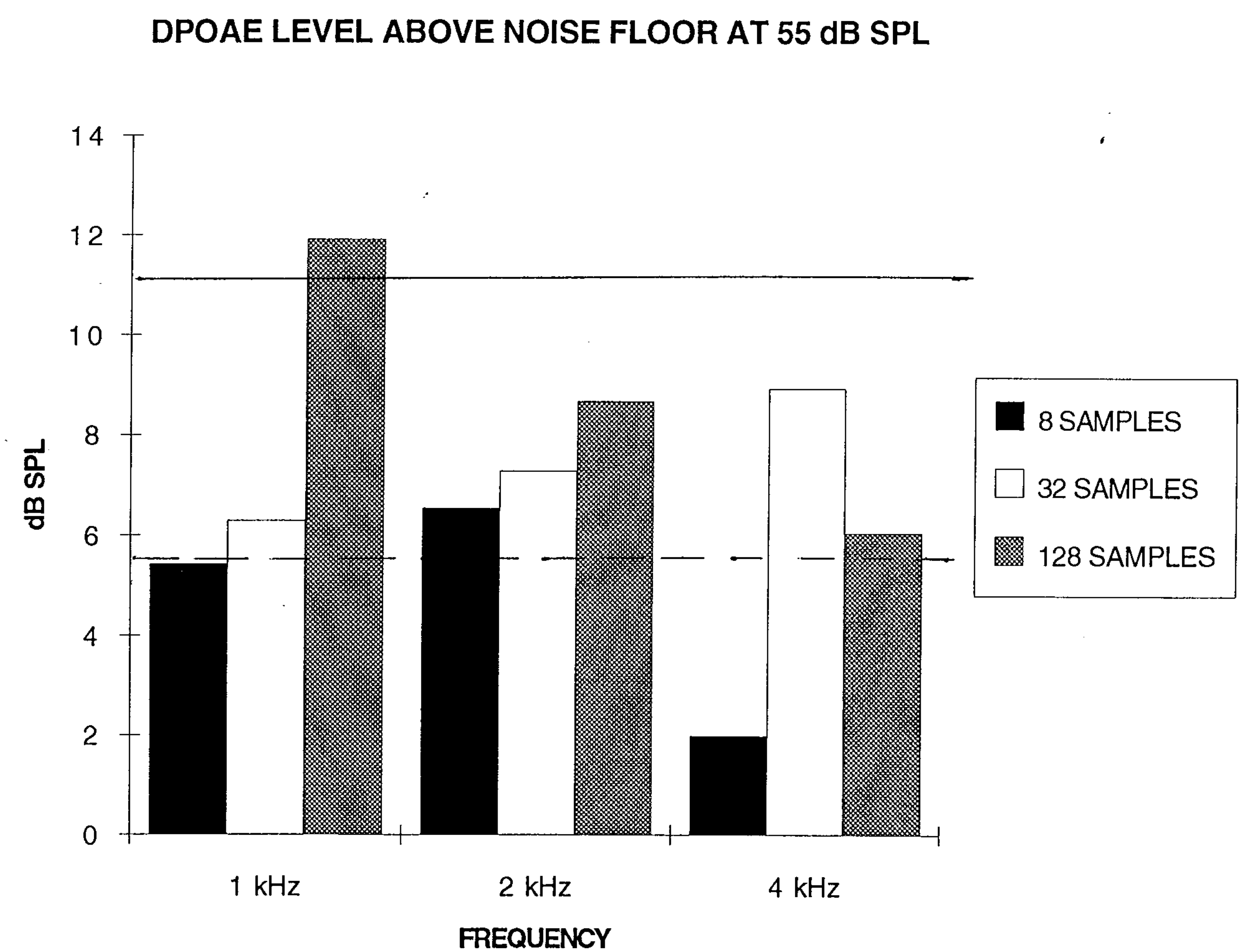


Figure 6. *DPOAE level above the noise floor for each frequency and time average at 55 dB SPL stimulus intensity level. The horizontal dotted line represents a 5.5 dB SPL criterion; the solid line represents the 11 dB SPL criterion.*

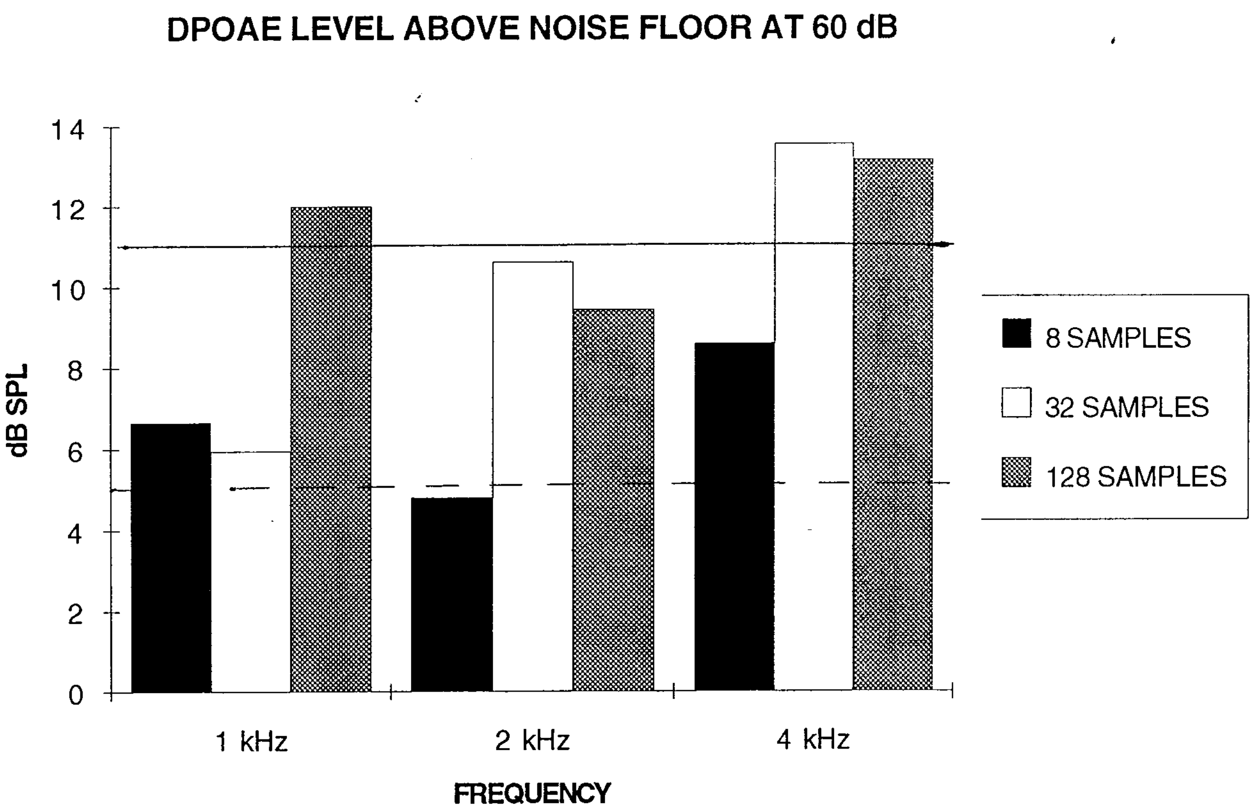


Figure 7. *DPOAE level above the noise floor for each frequency and time average at 60 dB SPL stimulus intensity level. The horizontal dotted line represents a 5.5 dB SPL criterion; the solid line represents the 11 dB SPL criterion.*

AVERAGE (AND RANGE) OF NOISE FLOOR MEASURES AS A FUNCTION OF NUMBER OF SAMPLES

	1 kHz	2 kHz	4 kHz
8 samples	**-1.98** (-9.64, 8.27)	**-11.58** (-16.54, 7.37)	**-7.26** (-12.5, 1.74)
32 samples	**-5.67** (-12.86, 10.05)	**-18.37** (-23.49, .58)	**-13.7** (-24.11, -3.53)
128 samples	**-10.93** (-19.17, 8.04)	**-22.97** (-31.94, -6.96)	**-15.04** (-29.66, -3.38)

Table 1. *This table shows the average and range of noise floors for all frequencies and time averages.*

11 dB CRITERION

	1 kHz	2 kHz	4 kHz
8 samples	75 dB SPL	70 dB SPL	70 dB SPL
32 samples	70 dB SPL	60 dB SPL	60 dB SPL
128 samples	55 dB SPL	65 dB SPL	60 dB SPL

Table 2. *Using a strict criterion (11 dB SPL), this table shows at what level valid emissions are found for each frequency and number of time averages.*

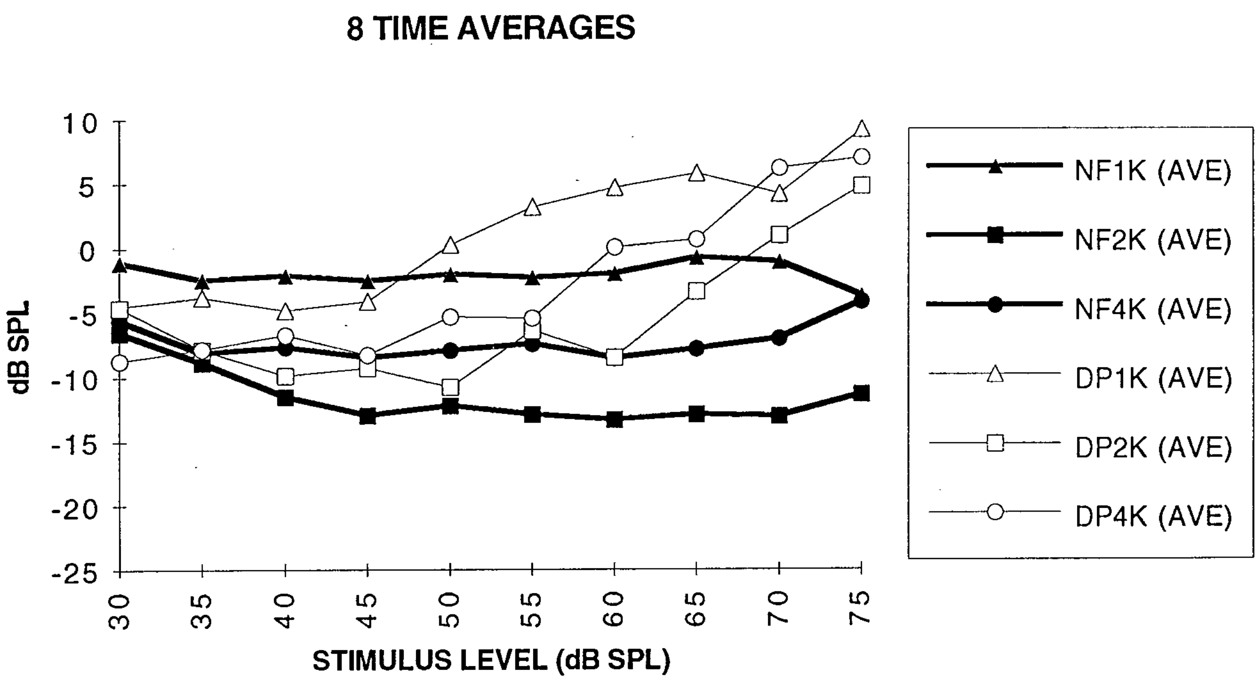
5.5 dB CRITERION

	1 kHz	2 kHz	4 kHz
8 samples	55 dB SPL	55 dB SPL	60 dB SPL
32 samples	55 dB SPL	50 dB SPL	50 dB SPL
128 samples	45 dB SPL	55 dB SPL	40 dB SPL

Table 3. *Using a less strict criterion (5.5 dB SPL), this table shows at what level valid emissions are found for each frequency and number of time averages.*

APPENDIX A

Figures:



8 TIME AVERAGES
10
5
0
-5
-10
-15
-20
-25
dB SPL
30
35
40
45
50
55
60
65
70
75
STIMULUS LEVEL (dB SPL)
NF1K (AVE)
NF2K (AVE)
NF4K (AVE)
DP1K (AVE)
DP2K (AVE)
DP4K (AVE)

Figure A-1.

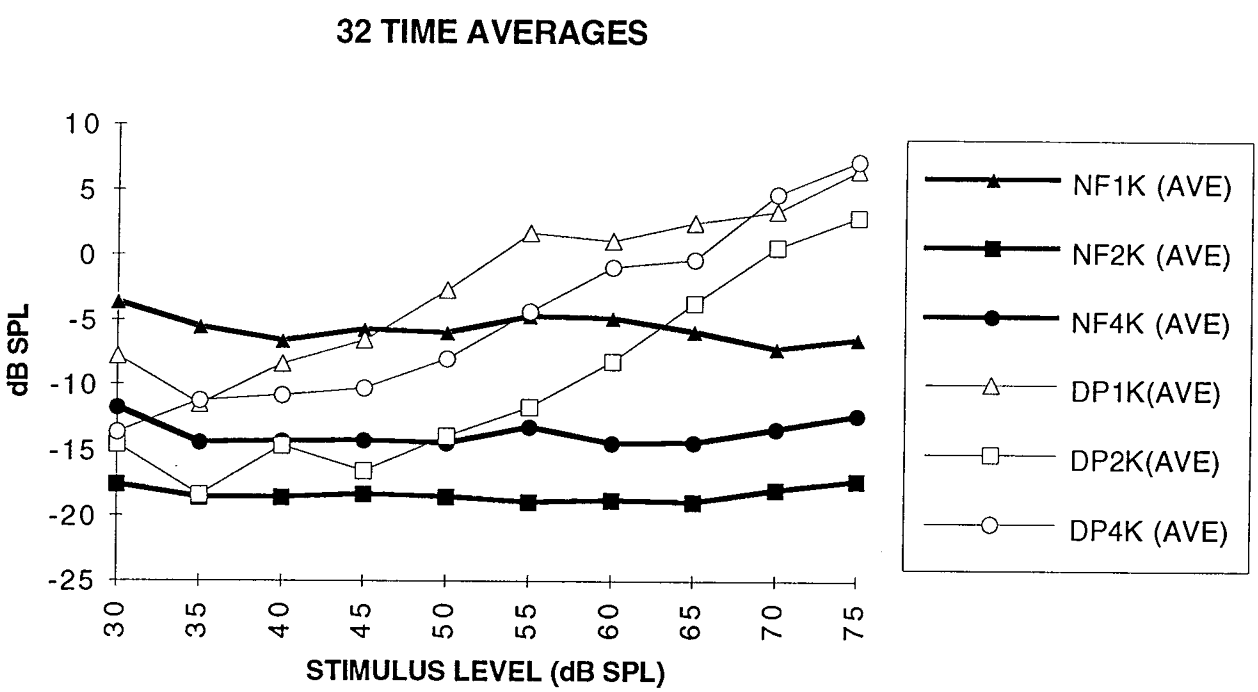
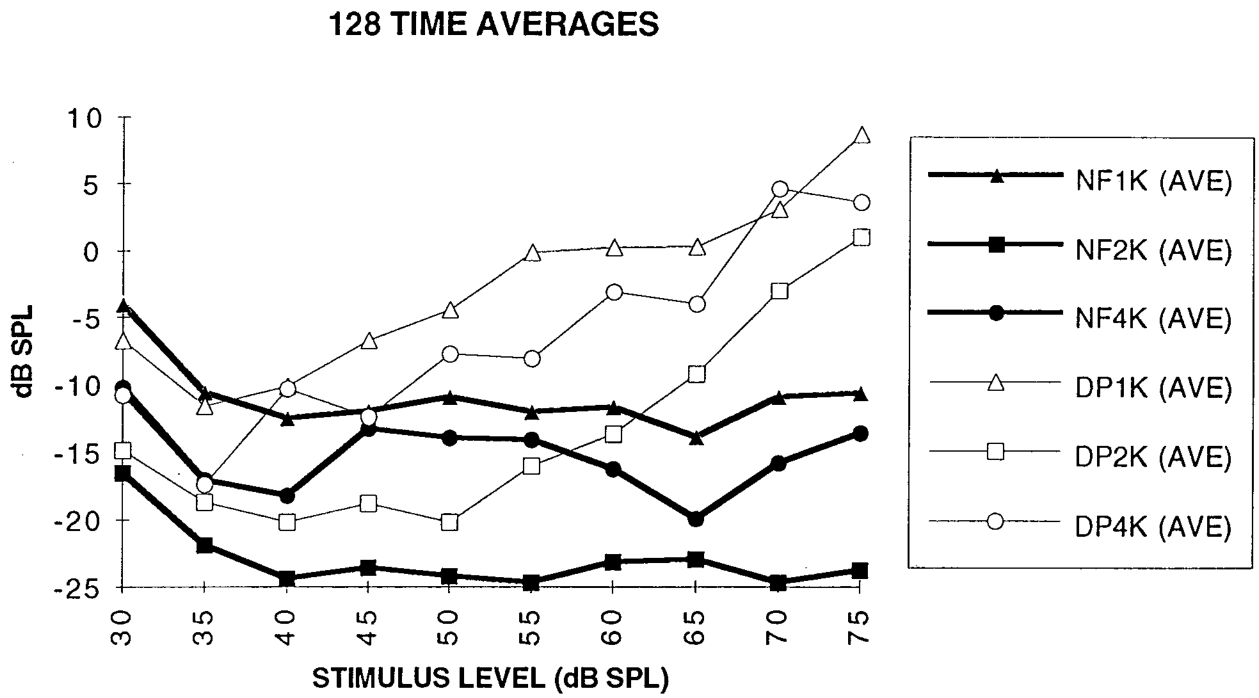

32 TIME AVERAGES
dB SPL
10
5
0
-5
-10
-15
-20
-25
30
35
40
45
50
55
60
65
70
75
STIMULUS LEVEL (dB SPL)
NF1K (AVE)
NF2K (AVE)
NF4K (AVE)
DP1K(AVE)
DP2K(AVE)
DP4K (AVE)

Figure A-2.



128 TIME AVERAGES
dB SPL
10
5
0
-5
-10
-15
-20
-25
30
35
40
45
50
55
60
65
70
75
STIMULUS LEVEL (dB SPL)
NF1K (AVE)
NF2K (AVE)
NF4K (AVE)
DP1K (AVE)
DP2K (AVE)
DP4K (AVE)

Figure A-3.

NOISE FLOOR AND DPOAEs AT 8 TIME AVERAGES (1 kHz)

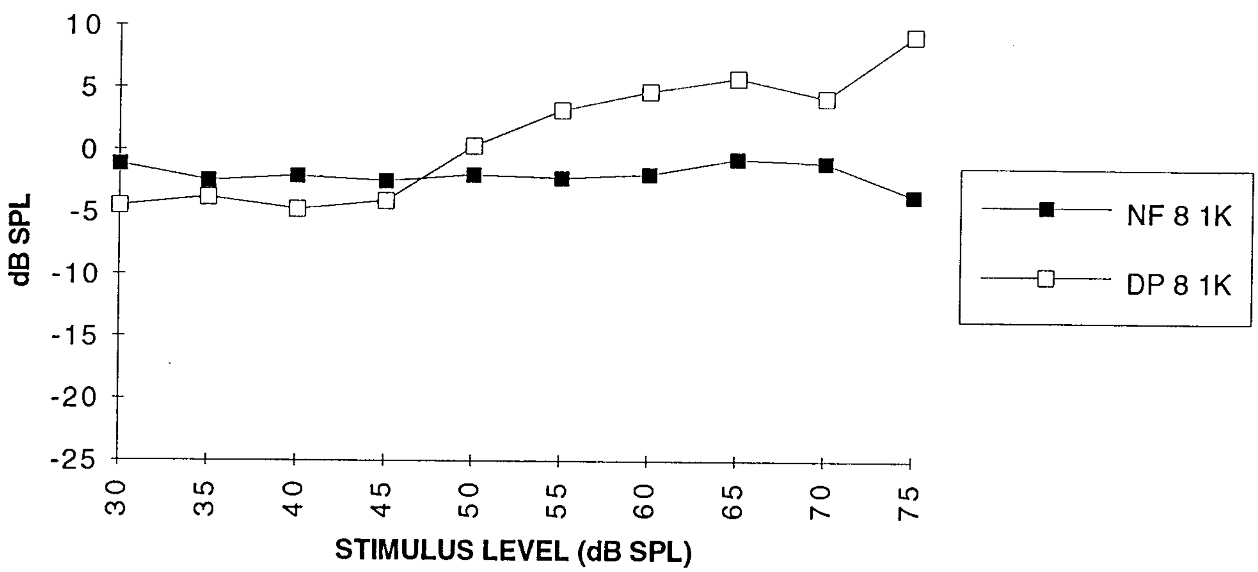


Figure A-4.

NOISE FLOOR AND DPOAEs AT 32 TIME AVERAGES (1kHz)

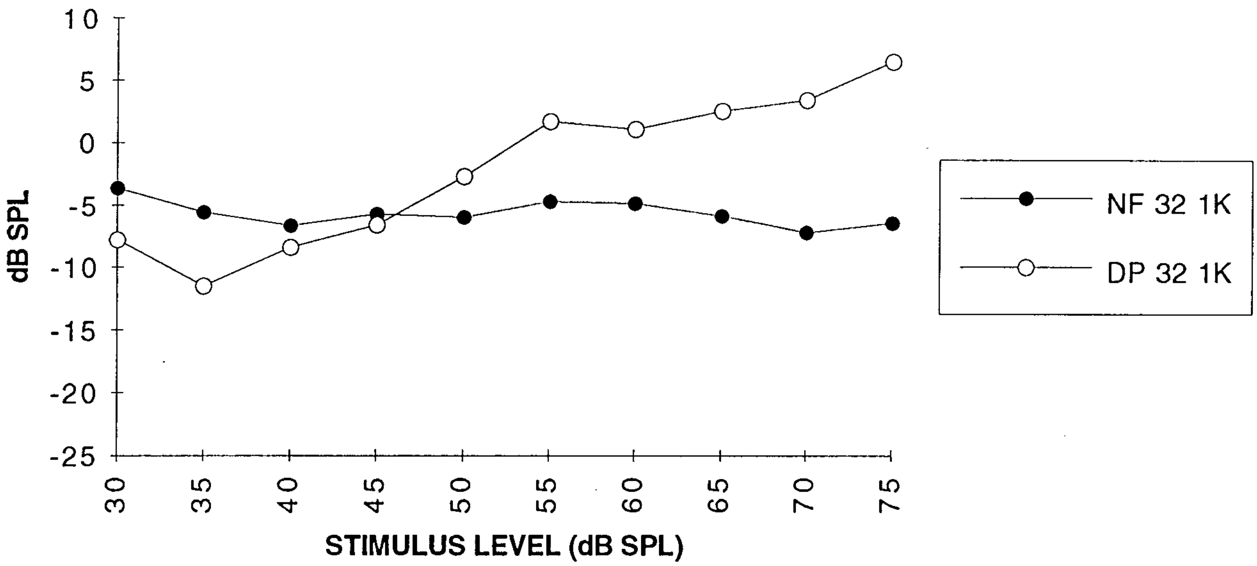


Figure A-5.

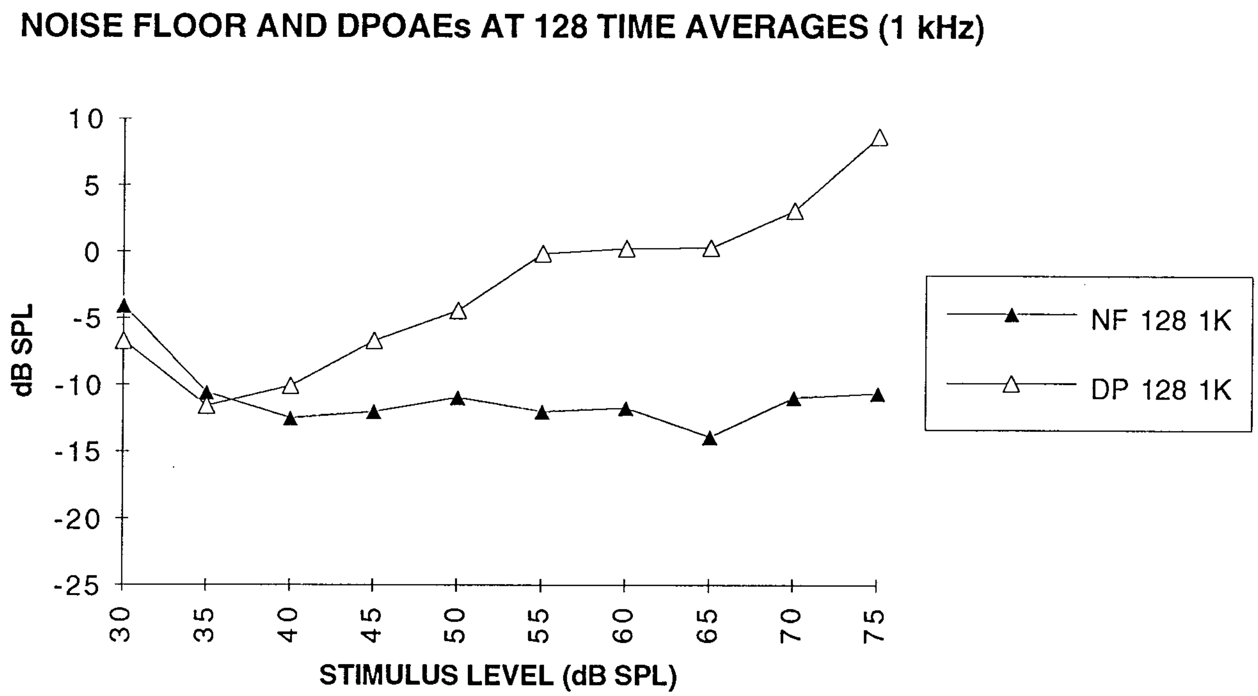

NOISE FLOOR AND DPOAEs AT 128 TIME AVERAGES (1 kHz)
dB SPL
10
5
0
-5
-10
-15
-20
-25
30
35
40
45
50
55
60
65
70
75
STIMULUS LEVEL (dB SPL)
NF 128 1K
DP 128 1K

Figure A-6.

NOISE FLOOR AND DPOAEs AT 8 TIME AVERAGES (2 kHz)

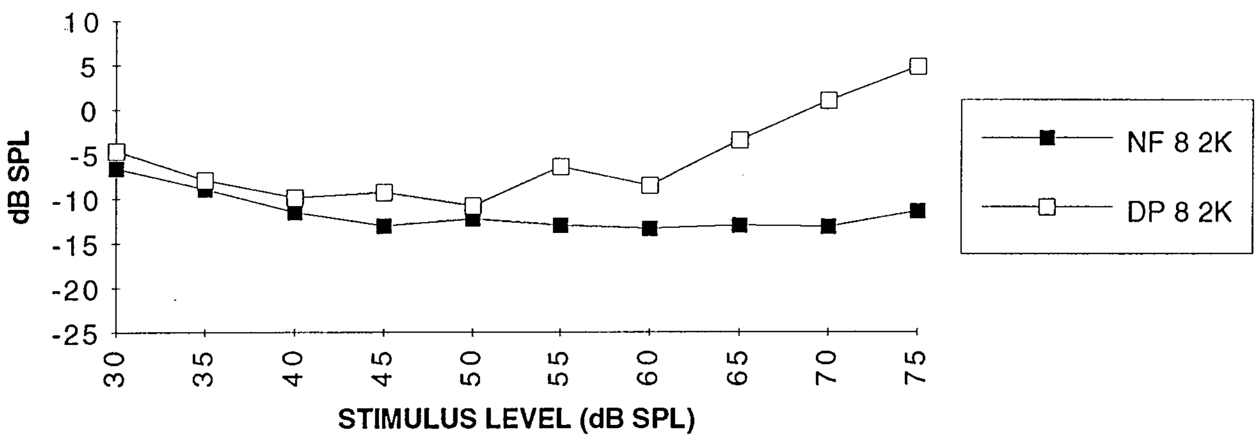


Figure A-7.

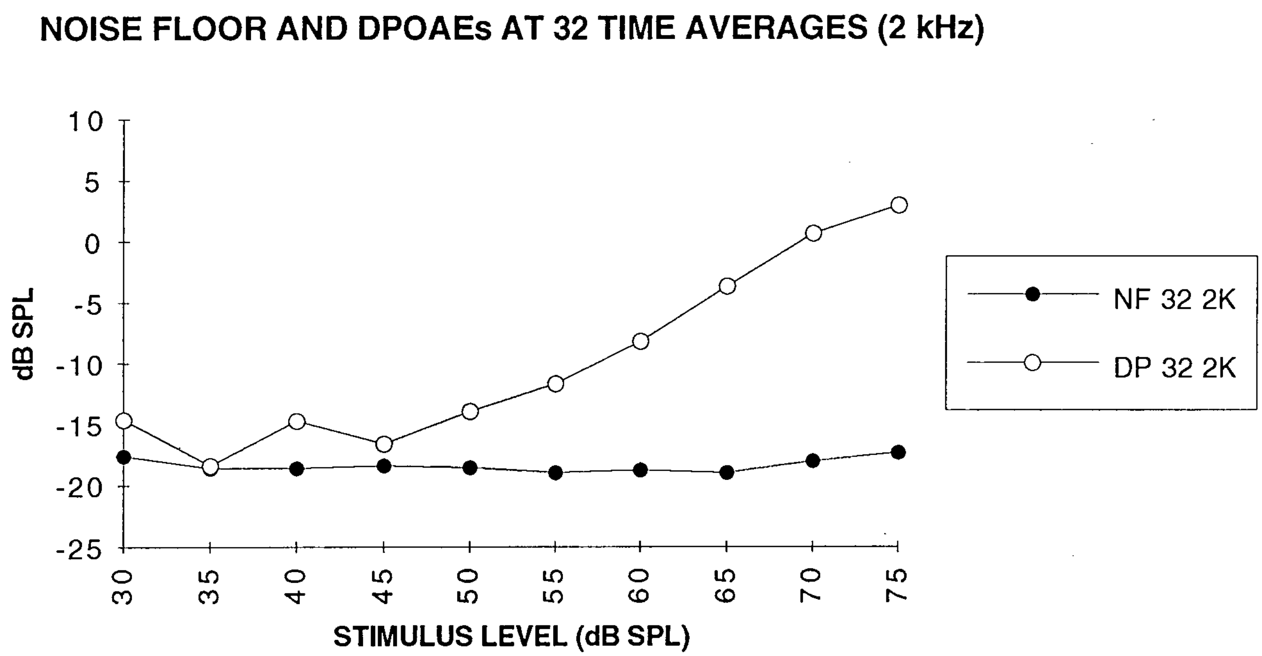

NOISE FLOOR AND DPOAEs AT 32 TIME AVERAGES (2 kHz)
dB SPL
10
5
0
-5
-10
-15
-20
-25
30
35
40
45
50
55
60
65
70
75
STIMULUS LEVEL (dB SPL)
NF 32 2K
DP 32 2K

Figure A-8.

NOISE FLOOR AND DPOAEs AT 128 TIME AVERAGES (2 kHz)

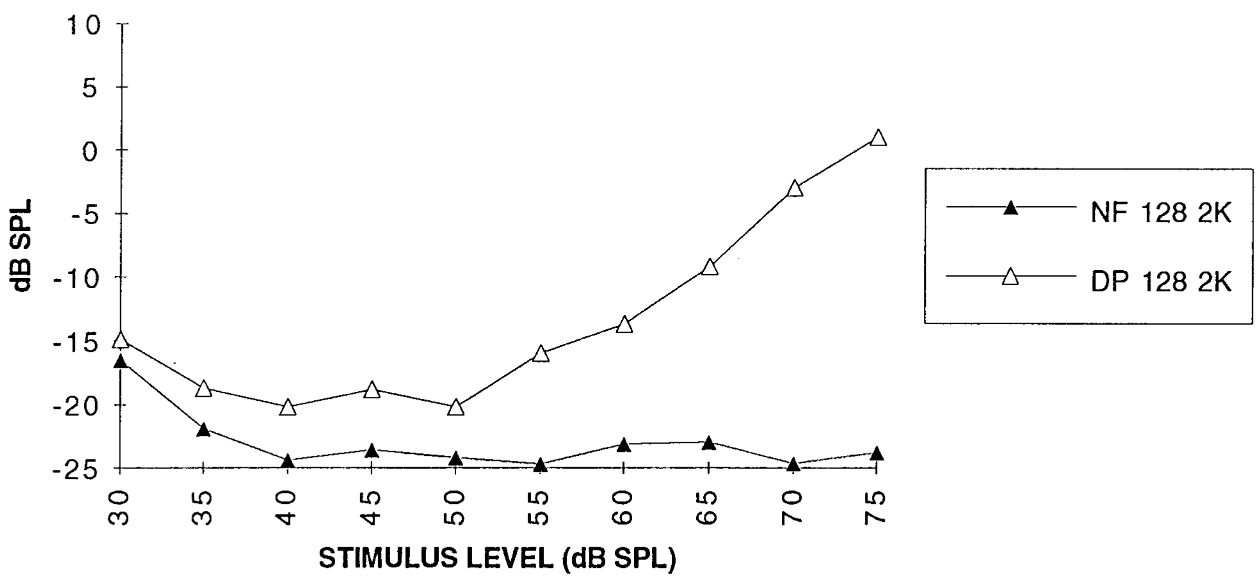


Figure A-9.

NOISE FLOOR AND DPOAEs AT 8 TIME AVERAGES (4 kHz)

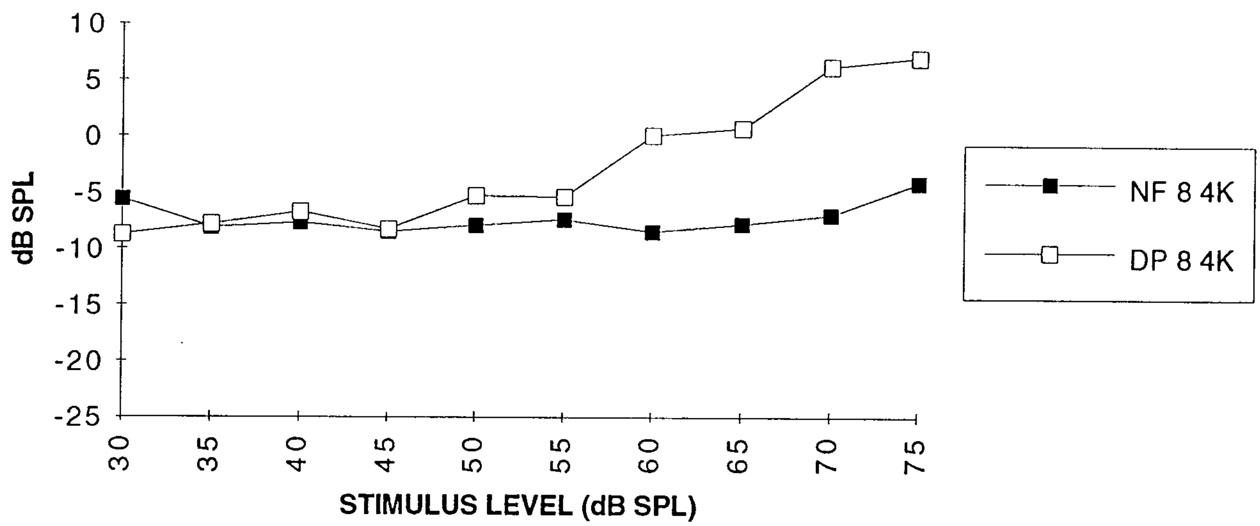


Figure A-10.

NOISE FLOOR AND DPOAEs AT 32 TIME AVERAGES (4 kHz)

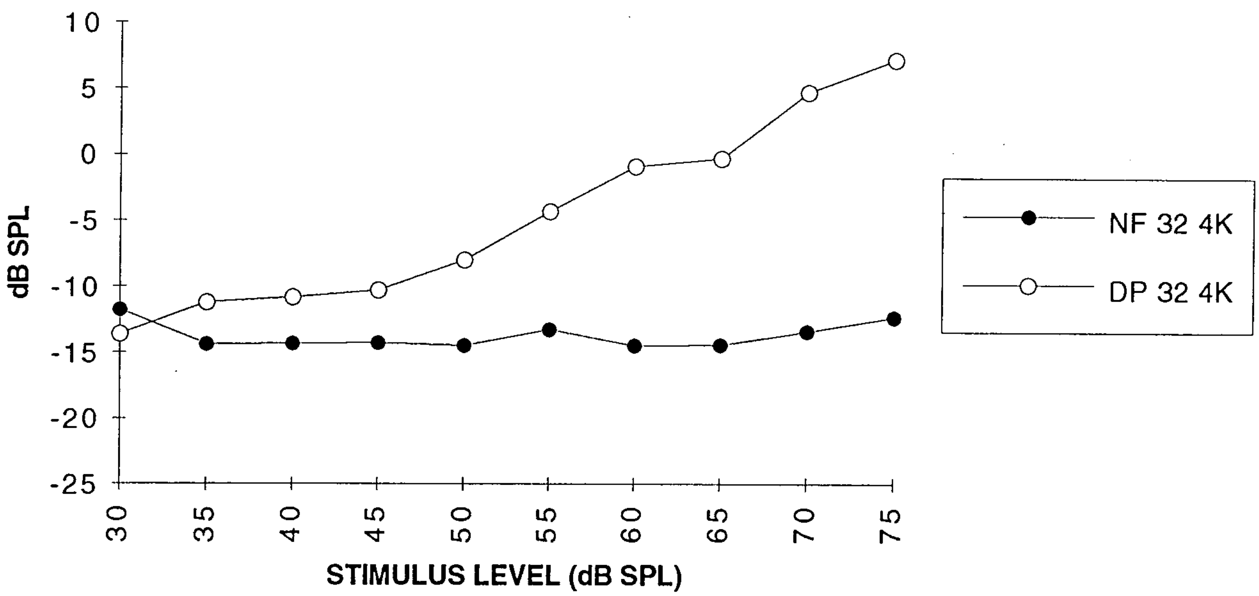


Figure A-11.

NOISE FLOOR AND DPOAEs AT 128 TIME AVERAGES (4 kHz)

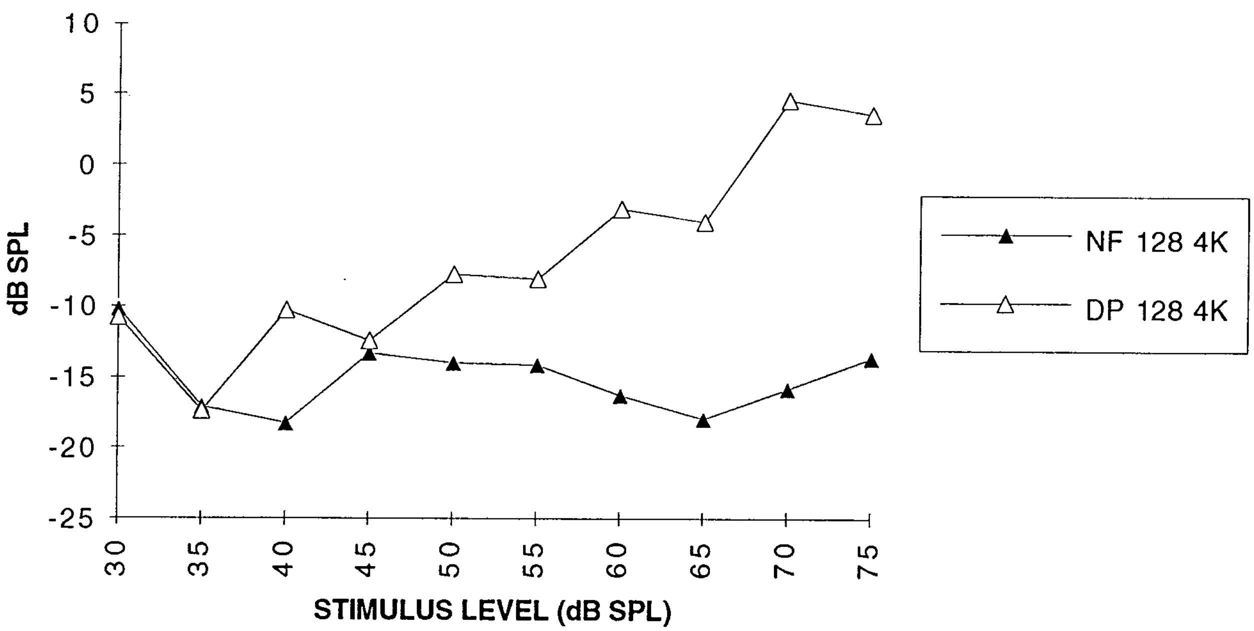


Figure A-12.

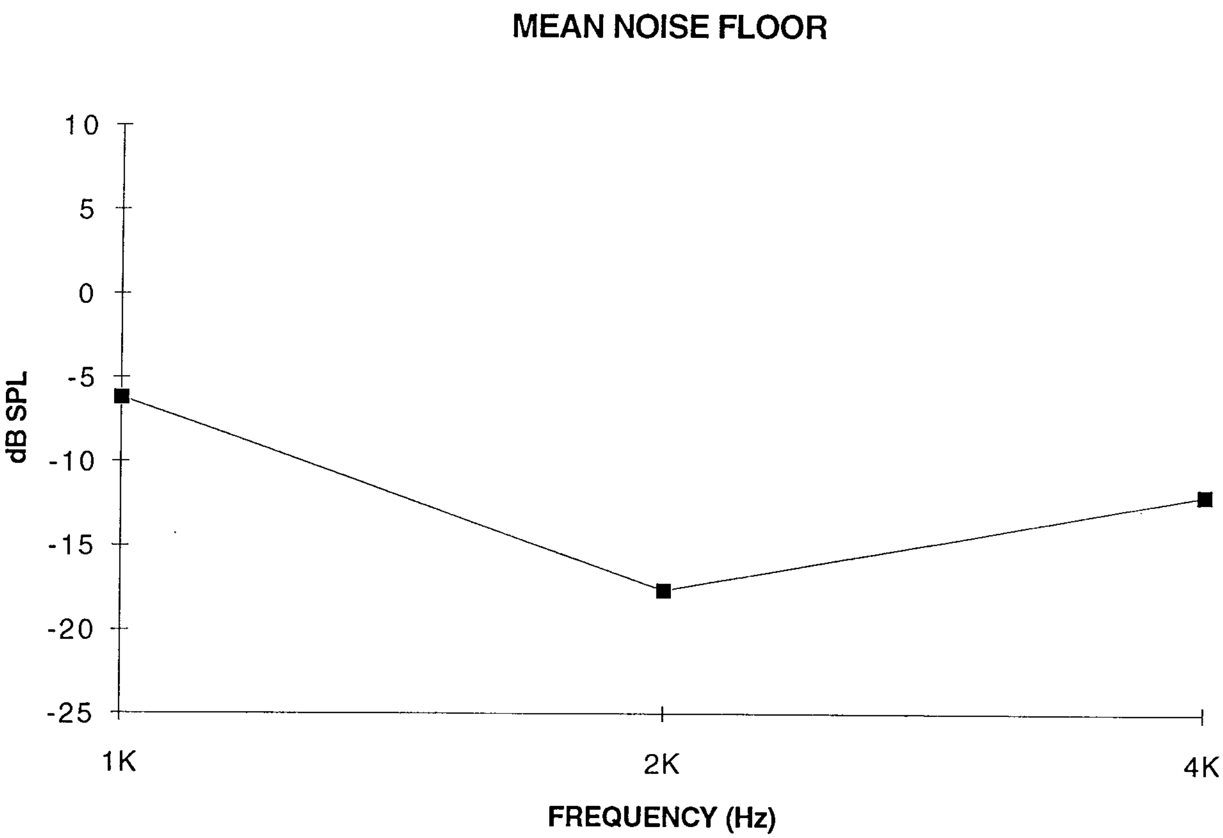


Figure A-13.